Estimating the Frequency, Magnitude and Recurrence of Extreme Cyclones in Northern Indian Ocean

Ali Hassan Baaqeel[1],Yahya Ali Daghreri[2],Sultan Abdullah Bin Hajlaa[3] andHadiHussain Al-Yami[4]

1)Manager, Health, Safety and Environment, Economic Cities Ports, King Abdullah Economic City, Saudi Arabia.
2)Country Manager K.S.A, Arabia Weather Inc., Jeddah, Saudi Arabia.
3)Manager, Tides and Notice to MarinersDepartment, General Commission for Survey, Jeddah, Saudi Arabia.
4)Commander Officer, medical evacuation and disaster management officer, Health Affairs, National Guard, Riyadh, Saudi Arabia.
Hajlaa.s@hotmail.com

Abstract*: Humans coexist with extreme events all the time, only when the intensity of the event becomes greater than a certain level there is a resulting disaster. Tropical cyclones are the most devastating of all natural disasters in terms of the loss of human life, property damage, and other economic consequences. Statistical analysis reveals that larger events occur less frequently than small events. In a year, we would have many values for the events; the annual maximum is the greatest of those values. Within an annual series, only the largest value per year is allowed, even if an additional significant peak occurred. As the magnitude of a hazardous increases, the frequency of occurrence (how often a given magnitude is equaled or exceeded) decreases. Thus, major disasters result from a small number of large events that rarely occur. A plot of recurrence intervals versus associated magnitudes produces a group of points that also approximates a straight line on semi-logarithmic paper. Therefore, past records of Cyclones at the northern Indian ocean, for years from1974 to2015 are used to predict future conditions concerning the annual frequency, the return period, the percentage probability for each event, and the probability of a certain-magnitude cyclones occurring in the region during any period.*

Keywords*: Tropical Cyclones, Indian Ocean, North Indian Ocean, Probabilities, Returns Period.*

I. Introduction

One of the most destructive disaster of nature is a severe cyclone and its destroying effects. If the cyclone occurs in a populated area, it may cause many deaths and injuries and extensive property damage regions. The ultimate goal of cyclones hazard assessment and risk evaluation for a particular site or area is to condense meteorological knowledge and experience into parameters used for predicting cyclones parameters which in turn can be applied by engineers in design and subsequent cyclonesnearby resistant areas.
Statistical surveys support researches on the likelihood of future cyclones. A primary goal of cyclones research is to increase the reliability of cyclone probability estimates. With a greater understanding of the hazard parameters of cyclones, we may be able to reduce damage and loss of life from this destructive event. Statistics help us to predict the future events based on previous events.

1.1 Tropical Cyclones

A **tropical cyclone**is a rapidly rotating storm system characterized by a low-pressure center, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain. Depending on its location and strength, a tropical cyclone is referred to by names such as hurricane, typhoon, tropical storm, cyclonic storm, tropical depression, and simply cyclone [1].

Cyclones Hurricanes, and typhoons are all the same weather phenomenon; use different names is used for these storms in different places. In the Atlantic and Northeast Pacific, the term “hurricane” is used. The same type of disturbance in the Northwest Pacific is called a “typhoon” and “cyclones” occur in the South Pacific and Indian Ocean [2]

Tropical cyclones typically form over large bodies of relatively warm water. They derive their energy through the evaporation of water from the ocean surface, which ultimately re-condenses into clouds and rain when moist air rises and cools to saturation. This energy source differs from that of mid-latitude cyclonic storms, such as nor'easters and European windstorms, which are fueled primarily by horizontal temperature contrasts. The strong rotating winds of a tropical cyclone are a result of the conservation of angular momentum imparted by the Earth's rotation as air flows inwards toward the axis of rotation. As a result, they rarely form within 5° of the equator [3]. Tropical cyclones are typically between 100 and 2,000 km (62 and 1,243 mi) in diameter.

Worldwide, tropical cyclone activity peaks in late summer, when the difference between temperatures aloft and sea surface temperatures is the greatest. However, each particular basin has its own seasonal patterns. On a worldwide scale, May is the least active month, while September is the most active month. November is the only month in which all the tropical cyclone basins are active [4] and [5].

Tropical cyclones forming between 5 and 30 degrees North latitude typically move toward the west. Sometimes the winds in the middle and upper levels of the atmosphere change and steer the cyclone toward the north and northwest. When tropical cyclones reach latitudes near 30 degrees North, they often move northeast [6].

Figure 1, the map is showing Cyclones, Hurricanes, and Typhoons and Their Respective Locations around the World around the earth equator with estimated time of active cyclones.

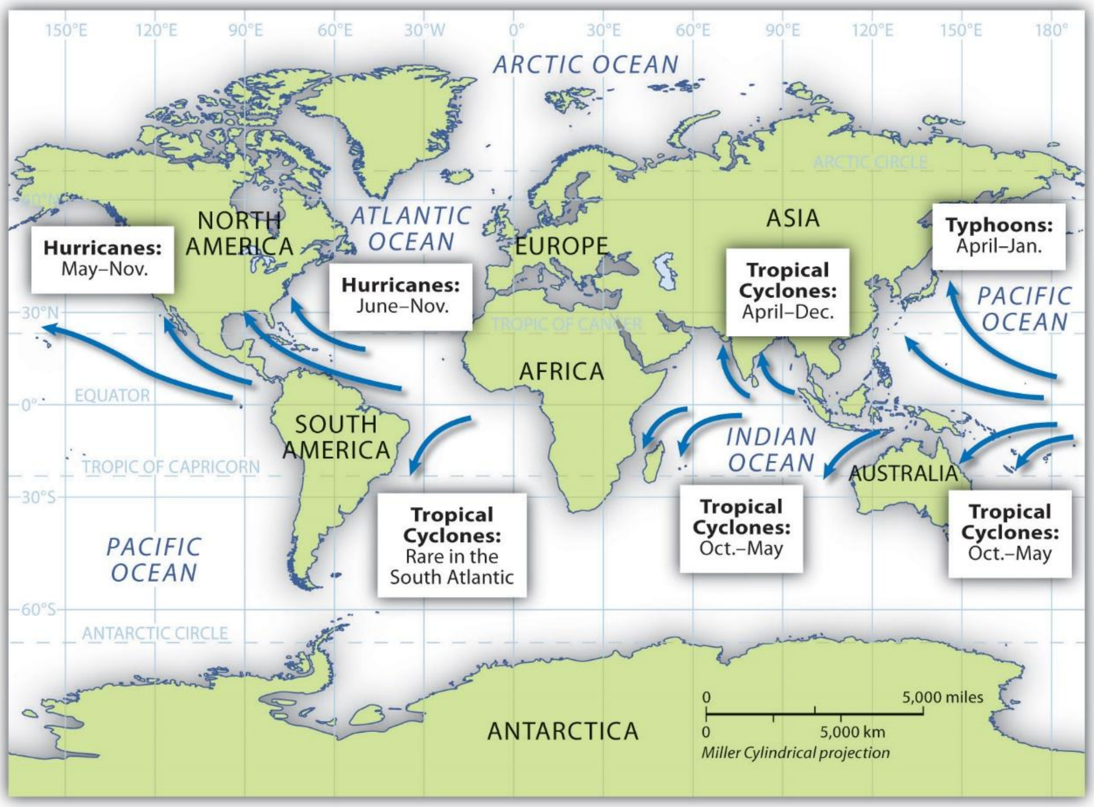

Figure 1: Cyclones, Hurricanes, and Typhoons and Their Respective Locations around the World [7].

Cyclones are measured by Saffir-Simpson Hurricane Wind Scale which is a 1 to 5 rating based on a cyclone's sustained wind speed. This scale estimates potential property damage. Cyclones reaching Category 3 and higher are considered major cyclones because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous, however, and require preventative measures. In the western North Pacific, the term "super typhoon" is used for tropical cyclones with sustained winds exceeding 241k/h [8].

Table 1: shows the wind speed and the pressure of each cyclone category, based on Saffir-Simpson scale [9] and [10].

Type	Category	Pressure (mb)	Winds (knots)	Winds (mph)	Types of Damage Due to Hurricane Winds
Depression	TD	-----	< 34	< 39	
Tropical Storm	TS	-----	34-63	39-73	
Hurricane	1	> 980	64-82	74-95	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
Hurricane	2	965-980	83-95	96-110	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
Hurricane	3	945-965	96-113	111-130	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
Hurricane	4	920-945	114-135	131-155	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
Hurricane	5	< 920	> 135	> 155	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

1.2 NorthernIndian Ocean Cyclones:

The **Indian Ocean** is the third largest of the world's oceanic divisions, covering 70,560,000 km^2 (27,240,000 sq mi) (approximately 20% of the water on the Earth's surface) [11]. It is bounded by Asia on the north, on the west by Africa, on the east by Australia, and on the south by the Southern Ocean or, depending on definition, by Antarctica [12].

Figure 2, shows the position of Indian Ocean, Northern Indian Ocean and the surrounding area relative to the map of the Kingdom of Saudi Arabia and India.

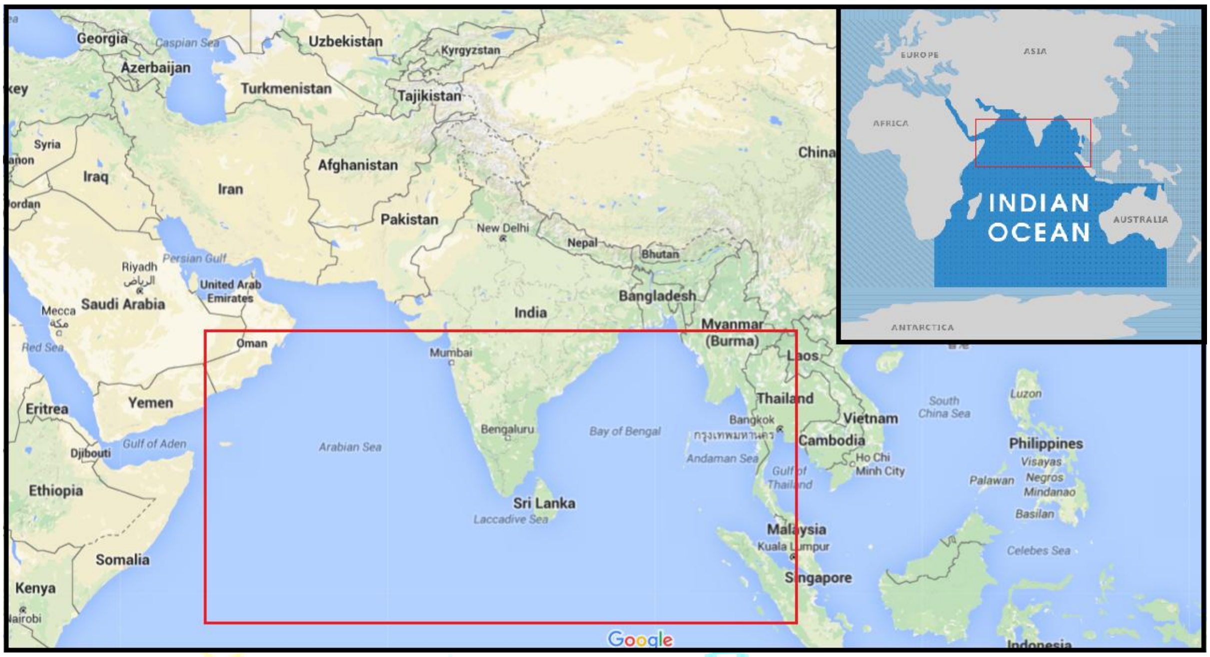

Figure 2: Location of Indian Ocean and its northern part on the world map [13].

The North Indian basin has a double peak of activity in May and November though tropical cyclones are seen from April to December. The severe cyclonic storms (>33 m/s winds [76 mph]) occur almost exclusively from April to June and late September to early December[14].

Figure 3, shows the Cumulative track map of all North Indian ocean cyclones from 1970 to 2005 [15].

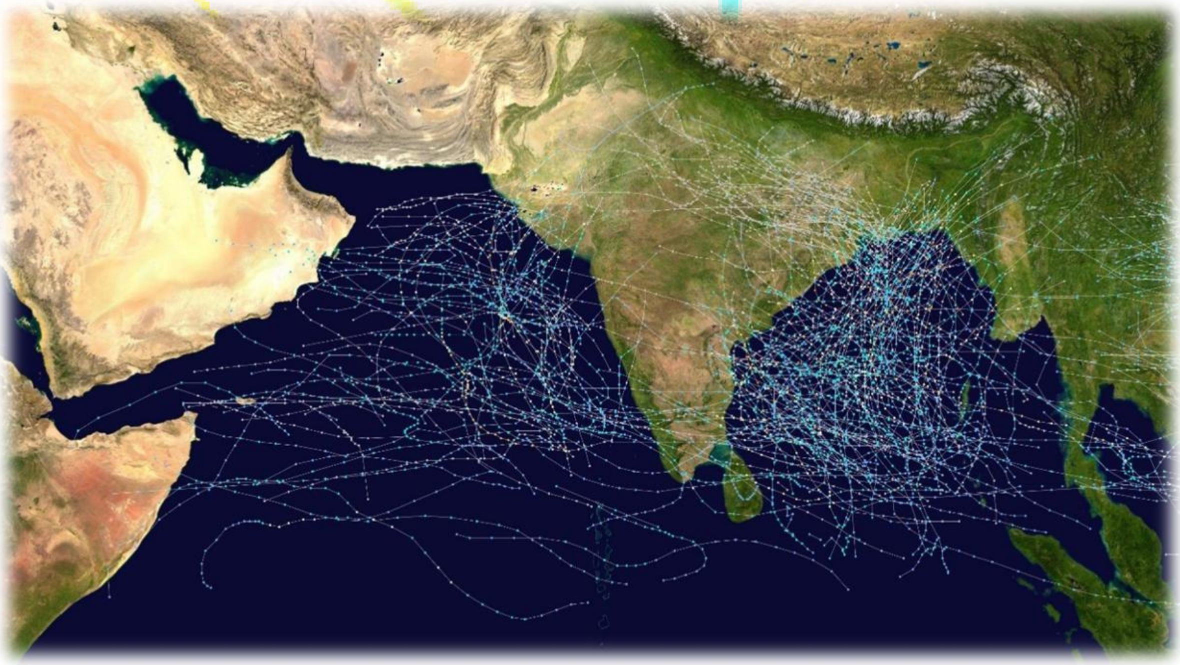

Figure 3. all North Indian ocean cyclones from 1970 to 2005 [15].

II. Literature Review

The term cyclone was first applied in reference to the tropical systems of the Indian Ocean. Sir Henry Piddington coined the word while stationed in India during the first half of the 19th century to describe the rotating nature of the wind fields of the violent storms observed in the Bay of Bengal [16]. In the SIO, TC research was likewise pursued in earnest by the latter half of the 19th century through British colonial resources. These early research efforts were conducted in great part by Charles Meldrum, inaugural director of the Royal Alfred Observatory and founding member of the Meteorological Society of Mauritius [17], [18]. Through collections of observations of wind direction and velocity, pressure, humidity, and cloud types both from Mauritius and from ocean vessel reports, he approximated TC paths across the SIO and advised ships at sea in TC avoidance tactics [17].

A significant disparity between cyclone mortality in developing and developed nations persists, though apart from simple casualty counts there is little information available on the epidemiology of cyclone morbidity and mortality in less developed countries. This indicates a need for additional research outside of the US. The United Nations Development Program (UNDP) identified 29 developing nations and four developed nations that are at risk for cyclones [19] but 42% and 27% of cyclone deaths in the past two centuries have occurred in Bangladesh and India, respectively [20]. Additionally, the majority of high-fatality storms occurred in the latter half of the 20th century though no developed nation sustained more than 1000 deaths from a cyclone in this time period[19], [21]. The leading explanations for regional differences in mortality is the size of the at risk population and the capacity for pre-event evacuation. Higher population densities in the Western Pacific and South East Asia where dense settlements in low lying areas are associated with increased risk of death in from storm surge [22], [23]. A higher economic development among the countries in the Americas is associated with lower regional mortality rates because of increased capacity to evacuate. Prior to the implementation of early warning, evacuation, and shelter systems an estimated 90% of cyclone mortality was attributed to storm surge drowning [24], [25], [26], [27], [28]. Improvements in forecasting, and early warning systems and in evacuation and shelter procedures, particularly in developed countries, have reduced storm-surge related mortality and increased proportional morbidity and mortality in the post-impact period [21], [29] and[30].

In addition, tropical cyclones frequency and strength are effected by variations in ocean temperatures which indicated by a weather patterns called El Niño and La Niña. El Niño and La Niña are opposite phases of what is known as the El Niño-Southern Oscillation (**ENSO**) cycle. The ENSO cycle is a scientific term that describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific (approximately between the International Date Line and 120 degrees West). La Niña is sometimes referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate [31].

Statistical theory of extreme values has been used to analyze the observed extremes of any phenomena and to forecast the further extremes based on the appropriate distribution, Gumbel [32]. This theory does not require analysis of the complete record of earthquake occurrence, but uses the sequence of earthquakes constructed from the largest values of the magnitude over a set of predetermined intervals.

III. EXTREME CYCLONESANALYSIS

Cyclones prediction can be considered into two types. First is the statistical prediction which is based on previous events; Data are collected from the records. Second is deterministic prediction which is made from the cyclones signs. Table 2 shows the data for cyclones in Northern Indian Ocean and surrounding area representing the minimum magnitude and maximum magnitude.

Most extreme event analysis is concerned with the distribution of annual maximum or minimum values at a given site. These events are given a rank, m, starting with $m = 1$ for the highest value, $m = 2$ for the next highest and so on in descending order. Each cyclone magnitude is associated with a rank, m, with $m = 1$ given to the maximum magnitude over the years of record, $m = 2$ given to the second highest magnitude, $m = 3$ given to the third highest one, etc. The smallest cyclone magnitude will receive a rank equal to the number of years over which there is a record, n. Thus, the discharge with the smallest value will have $m = n = 40$.

Table 2: Data for the cyclones in the Northern Indian Ocean from 1976 to 2015 [33].

Year	Number of Cyclones	Minimum Magnitude (knots)	Maximum Magnitude	
			(knots)	Category
2015	5	35	135	4
2014	5	35	115	4
2013	7	35	140	5
2012	4	35	55	TS
2011	6	35	80	1
2010	5	55	135	4
2009	5	35	65	1
2008	7	35	115	4
2007	6	45	140	5
2006	5	35	115	4
2005	7	25	65	1
2004	4	45	65	1
2003	4	35	85	2
2002	5	35	55	TS
2001	5	35	115	4
2000	4	35	65	1
1999	5	35	140	5
1998	8	35	105	3
1997	4	35	115	4
1996	8	40	115	4
1995	4	40	105	3
1994	5	40	125	4
1993	2	75	80	1
1992	12	35	70	1
1991	4	35	140	5
1990	4	25	125	4
1989	2	35	55	TS
1988	5	35	110	3
1987	8	35	55	TS
1986	3	45	55	TS
1985	6	55	60	TS
1984	4	45	85	2
1983	4	30	55	TS
1982	5	50	120	4
1981	3	60	75	1
1980	5	20	35	TS
1979	8	20	85	2
1978	4	40	90	2
1977	6	20	110	3
1976	14	20	55	TS

There are several formulas for calculating the probability value. The Weibull formula will be used because of its ease of use.

According to the Weibull equation, the return period or recurrence interval T (in years) is calculated using the following equation:

T (years)=(n+1)/m …………………………………….. (1)

Where:m=event ranking(in a descending order), and

n =numberofevents in the period ofrecord.

Thepercentageprobabilitythe(annualexceedanceprobability)foreachmagnitudeiscalculated using the inverseof theWeibull equationas follows:

P (percent)=100.m/(n+1) …………………………………….. (2)

Fromequations(1)and(2)itisclearthat$P$=100/T%.Forexample,acycloneequaltothatofa10-yearonewouldhaveanannualexceedanceprobabilityof1/10=0.1or10%.Thiswouldsaythatinanygivenyear,theprobabilitythata cyclonewithamagnitudeequaltoorgreaterthanthatofa10yearcyclonewouldbe0.1or10%.Similarly,the probability yofa cyclonewithamagnitudeex ceding the50yearoneinanygivenyearwouldbe1/50=0.02,or2%.Notethatsuchprobabilitiesarethesameforeveryyear,butin practice,sucha cyclone could occurnextyear, or beexceededseveraltimesin the next50years.

Table3showsthecalculationsoftherank$m$,theprobability$P$andthereturnperiod$T$forthedata oftheyearlymaximum magnitudegiven in Table 1.

Table 3: The rank, probability and the return period results.

Rank (m)	Year	Maximum Magnitude (knots)	Probability (P) %		Return Period (T)	
1	2013	140	2.44	Average= 6.097561	41.00	Average= 21.35
2	2007		4.88		20.50	
3	1999		7.32		13.67	
4	1991		9.76		10.25	
5	2015	135	12.20	Average= 13.414634	8.20	Average= 7.52
6	2010		14.63		6.83	
7	1994	125	17.07	Average= 18.292683	5.86	Average= 5.50
8	1990		19.51		5.13	
9	1982	120	21.95		4.56	
10	2014	115	24.39	Average= 30.487805	4.10	Average= 3.34
11	2008		26.83		3.73	
12	2006		29.27		3.42	
13	2001		31.71		3.15	
14	1997		34.15		2.93	
15	1996		36.59		2.73	
16	1988	110	39.02	Average= 40.243902	2.56	Average= 2.49
17	1977		41.46		2.41	
18	1998	105	43.90	Average= 45.121951	2.28	Average= 2.22
19	1995		46.34		2.16	
20	1978	90	48.78		2.05	
21	2003	85	51.22	Average= 53.658537	1.95	Average= 1.86
22	1984		53.66		1.86	
23	1979		56.10		1.78	
24	2011	80	58.54	Average=	1.71	Average=

25	1993		60.98	59.756098	1.64	1.68
26	1981	75	63.41		1.58	
27	1992	70	65.85		1.52	
28	2009	65	68.29	Average= 71.95122	1.46	Average= 1.39
29	2005		70.73		1.41	
30	2004		73.17		1.37	
31	2000		75.61		1.32	
32	1985	60	78.05		1.28	
33	2012	55	80.49	Average= 87.804878	1.24	Average= 1.14
34	2002		82.93		1.21	
35	1989		85.37		1.17	
36	1987		87.80		1.14	
37	1986		90.24		1.11	
38	1983		92.68		1.08	
39	1976		95.12		1.05	
40	1980	35	97.56		1.03	

IV. CYCLONES PARAMETERS

4.1 Annual Exceedance Probability and Return Period

ReturnperiodorRecurrenceintervalistheaverageintervaloftimewithinwhichafloodofspecifiedmagnitudeisexpectedtobeequaledorexceededatleastonce.41-yearscycloneisacyclonethatisexpectedtooccur,ontheaverage,onceevery41years,orhas2.44%chance of occurring eachyear.

Figure4isaplotofcyclonemagnitudeandannualexceedanceprobabilityrelationship(linearscales)withtheannualmaximummagnitudeperyearontheYaxisversustheannualexceedanceprobabilityon the X axis. TheXandY axes both uselinear scales.

Wend speed magnitudes are converted to cyclones strength category base on the range of wend speed for each Cyclone category (As explained in Table 1). As a result of this, the annual probability can have identified for each cyclone category. For example, the possibility of having Category 5 cyclones in every year is 0-13.4 %

Similarly,the possibility of having Category 1 cyclones in every year is 96-78%.

Theannualpeakinformationmayalsobepresentedwithalgorithm icratherthan alinearscale.This is often done to make the curve appear as straight line andalsotoavoidagraphthatwillsuggesteitherazerooraone–hundredpercentexceedchance probability.Moreover,a straight line curves are more easily allow extrapolation beyond data extremes.Figure5representsthecyclone magnitude and the annual exceedance probability (log scale) relationship.

Percentage probability is determined by dividing one by their recurrence interval and multiplyig by 100.Forexample,theprobabilitythatacyclonemagnitudewillexceedthe 41-year earthquake thisyear oranyotheryearwouldbe2.43%.

Figure6showsthecyclonemagnitudeandreturnperiodrelationshiponlinearscales.Fromthefigureitcanbenoticedthattheturnperiodofcategory 5cyclonesisabout7.5years,andcategory 1hasarecurrence interval of about 1.28year.

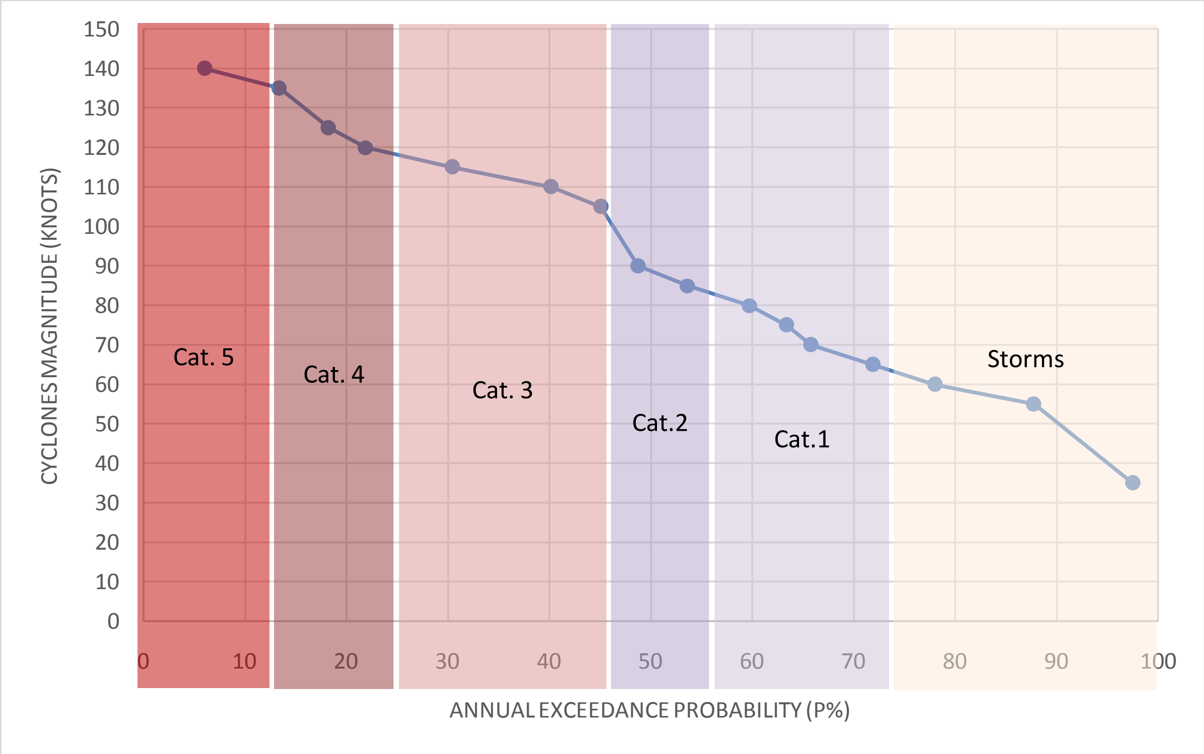

Figure 4: Cyclone magnitude and probability relationship (linear scales).

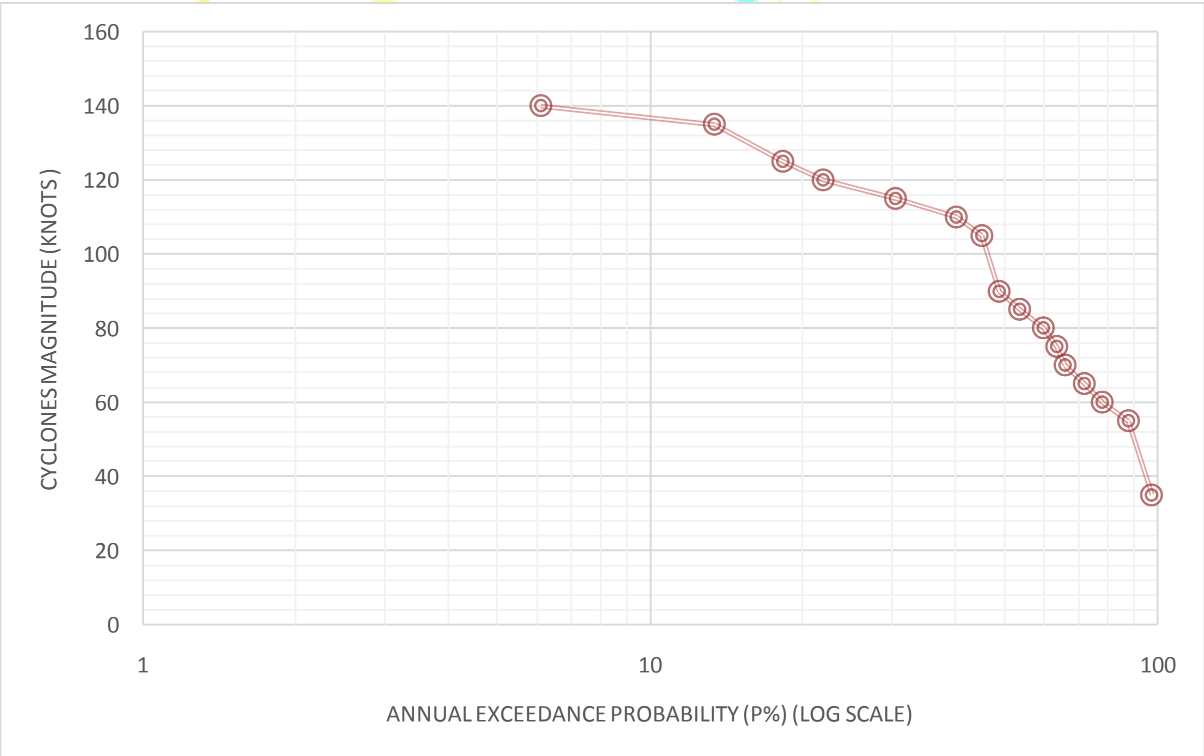

Figure 5: Cyclone magnitude and annual exceedance probability (log scale) relationship

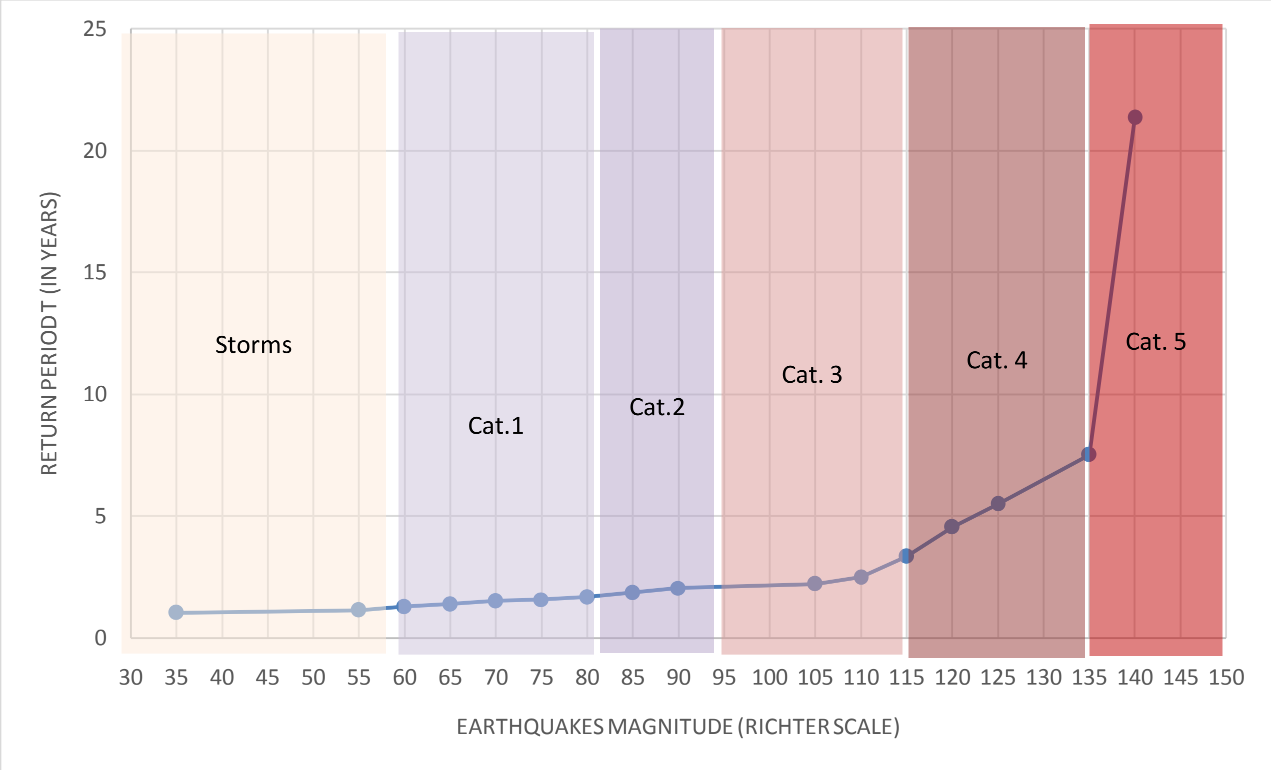

Figure 6: Cyclones magnitude and return period relationship (linear scales).

V. CONCLUSIONS AND POINTS FOR FUTURE RESEARCHES

5.1 Conclusions

Tropical Storms is an unavoidable natural disaster for the region. Hence, to take precautions for the future by utilizing the past experiences are very substantial. This can be a kind of a proposition to the higher authorities to have an open eye to this particular region.

In this study, the statistical frequency analyses are applied to the recorded annual maximum cyclones magnitudes for Northern Indian Oceansince 1976.

The cyclone hazard parameters are estimated, these are: the mean return periods (recurrence intervals), the frequency, the probability of cyclones occurrence (annual exceedance probability) for a given magnitude during any year, and the probability of earthquake occurrence for a given magnitude during a time span of *t*-years with a stress on a 40-year period. The Weibull equation is applied to estimate the return period, while the inverse of the Weibull equation is used to calculate the probability of occurrence.

5.2 Points for Future Researches

Points for future researches can be summarized as follows:

To study in details the period before 1976where it is included a recorded.

- To use other methods for evaluation of cyclones parameters and compare the obtained results.
- To estimate cyclones, hazard parameters for regions aroundArabian Sea.
- To estimate hazard parameters for other events like: floods, subsidence, volcanic eruptions and severe storms in different regions around Northern Indian Ocean.
- - To draw a cyclone map for Northern Indian Ocean region and for other regions around it.

To study the relation between El Niño and La Niña and number of cyclones in the Northern Indian Ocean.

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